Development of The Detector Array for Photons, Protons, and Exotic Residues

DAPPER

Alan B. McIntosh
Texas A&M University

NN2024

Acknowledgements

<u>Austin Abbott (Ph.D. 2024)</u>
<u>Arthur Alvarez</u>
Aaron Couture (LANL)
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Alan McIntosh
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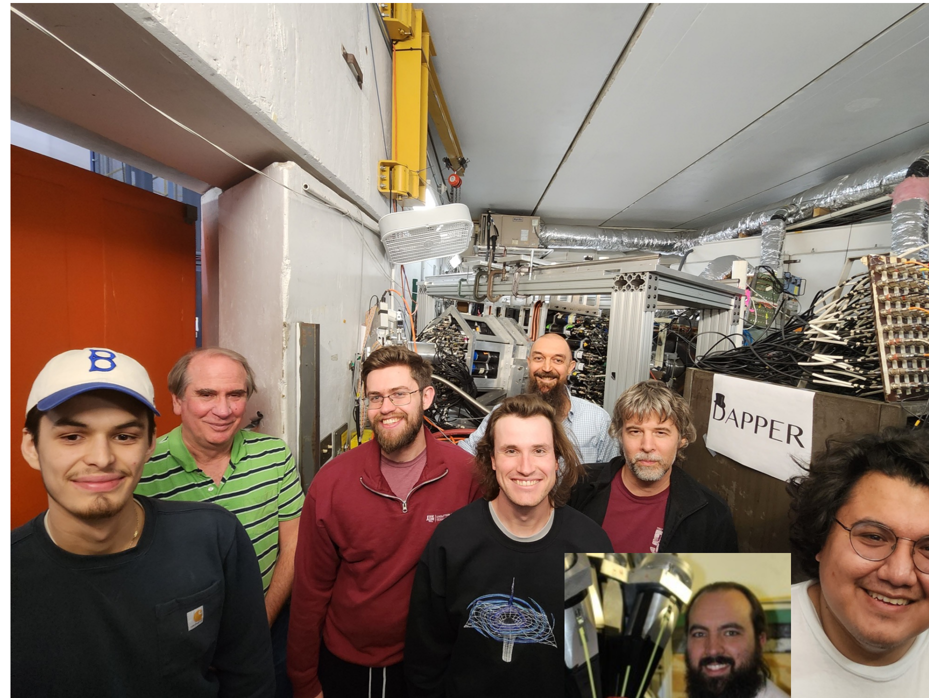
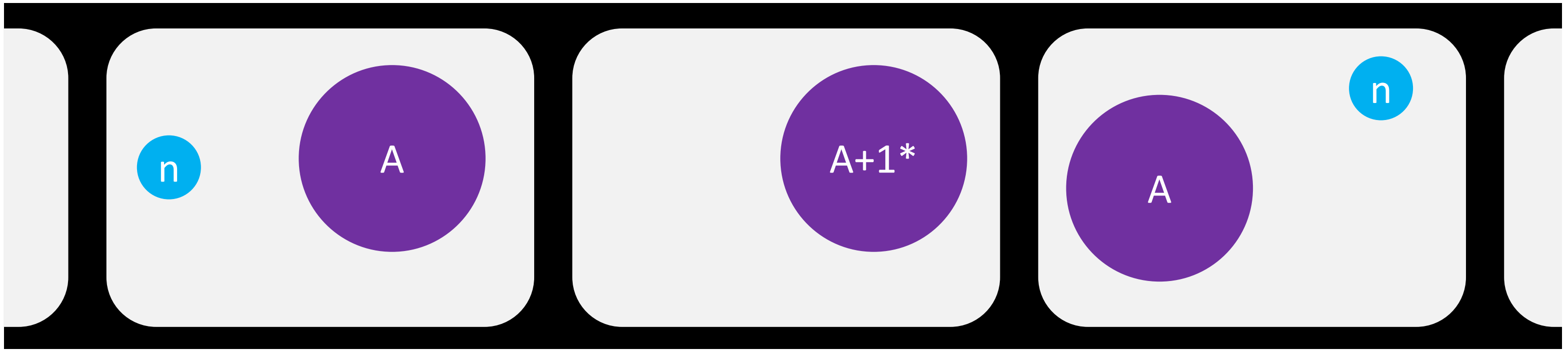


DAPPER



Photon Strength Function

A description of the bulk quantum mechanical component of photon emission.

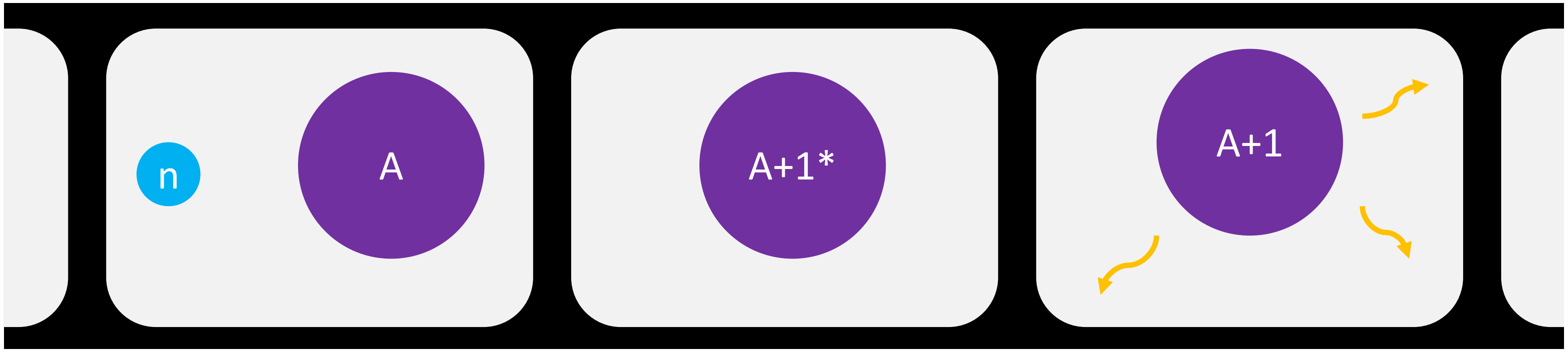
Stronger PSF

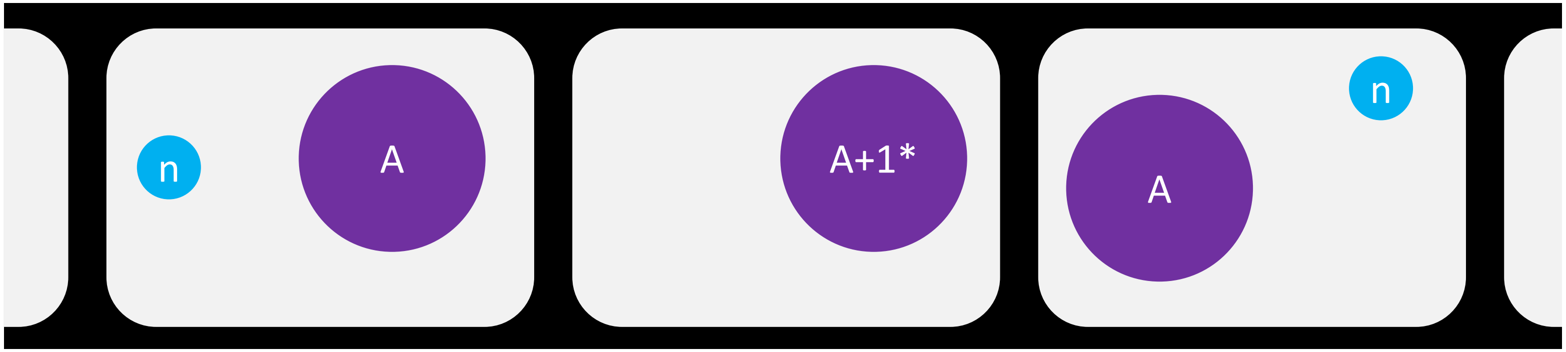
⬇

More "survivors"

Impact:

Fundamental science
Nuclear astrophysics
Nucleosynthesis
Stockpile science
Nuclear forensics
Reactor design





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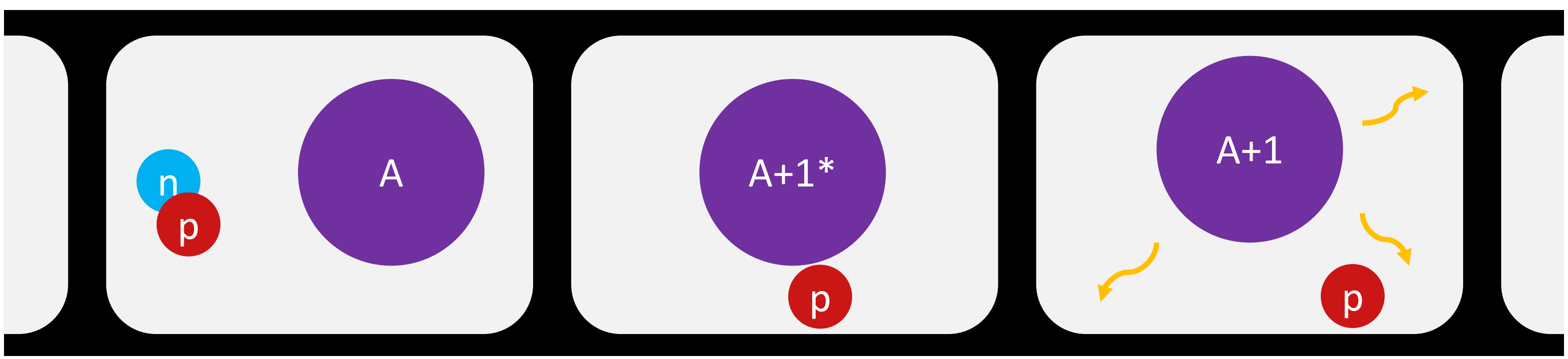
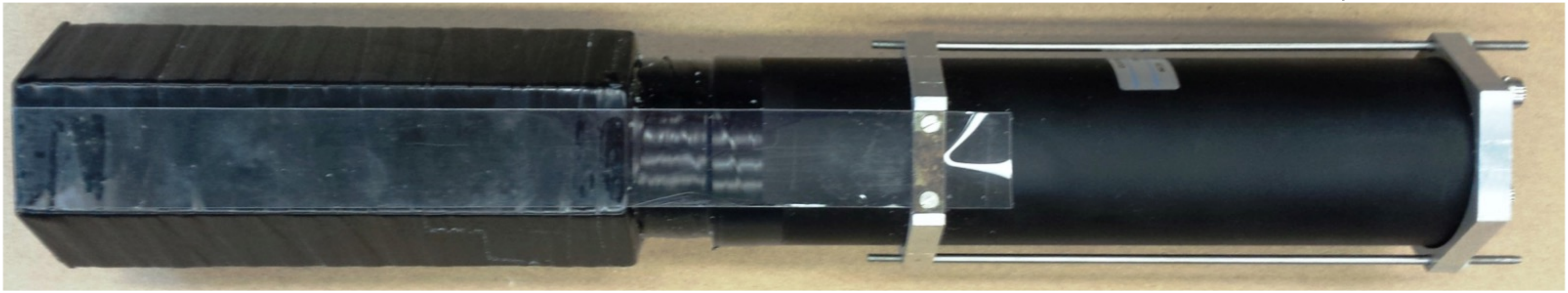


Surrogate reaction: (d,p) as proxy for (n,g)

- Produce many E* from single energy beam
- Determine E* from proton energy and angle
- Can be used for unstable nuclei

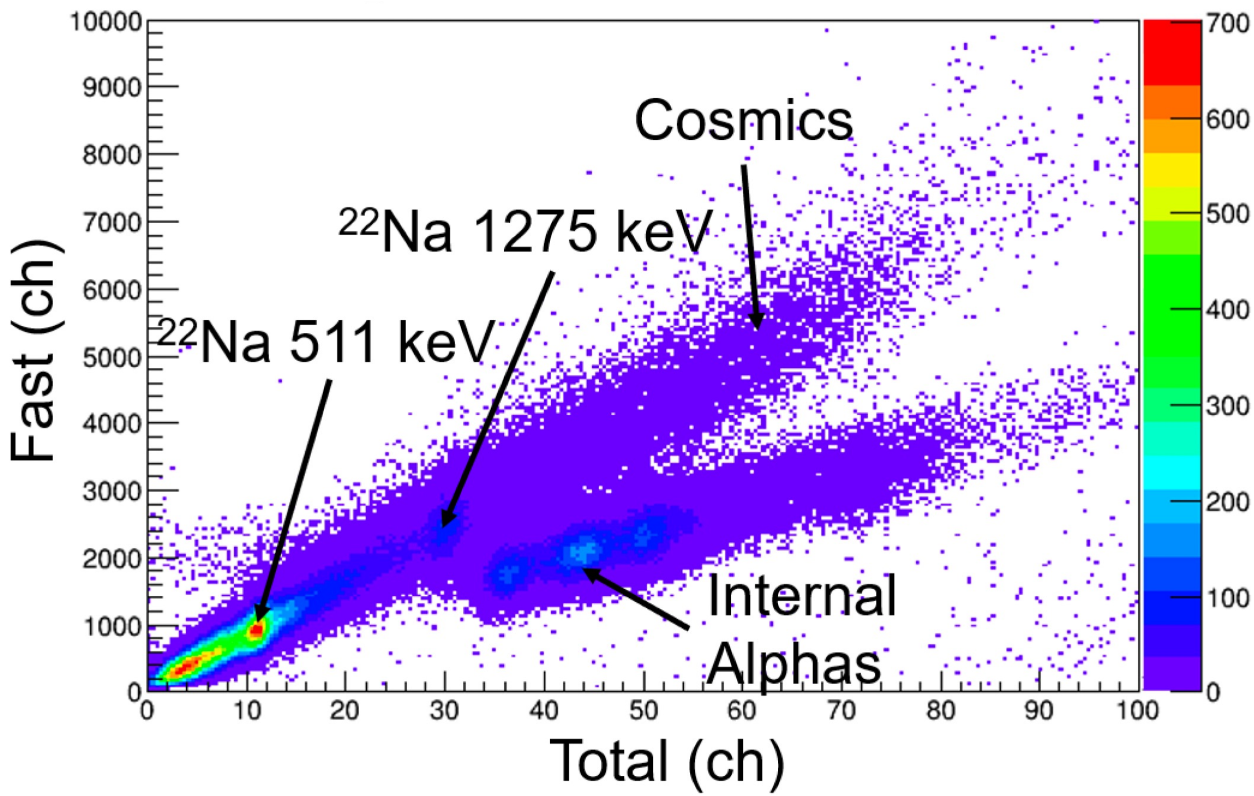
Barium Fluoride 128 modules

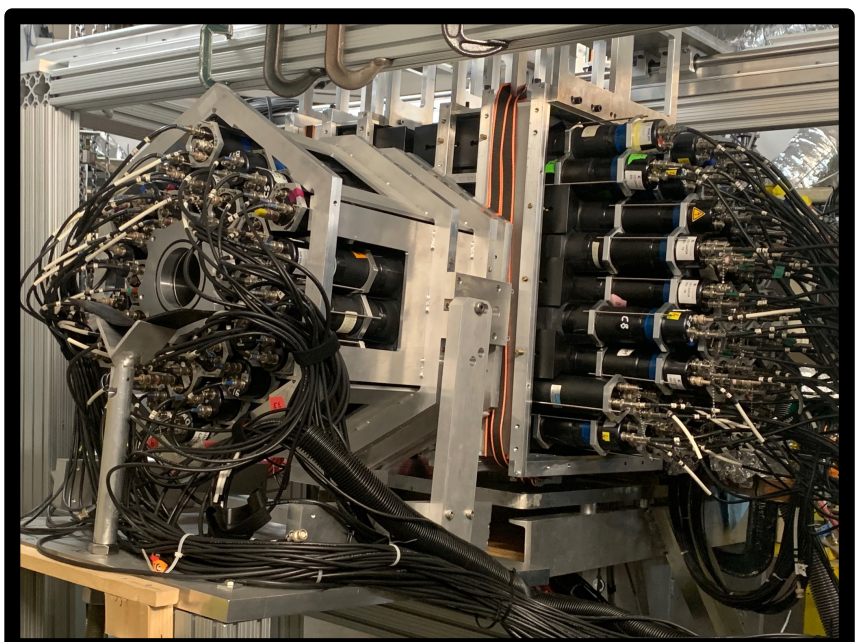
TAMU/ORNL BaF2



crystal 20 cm x 6.5 cm

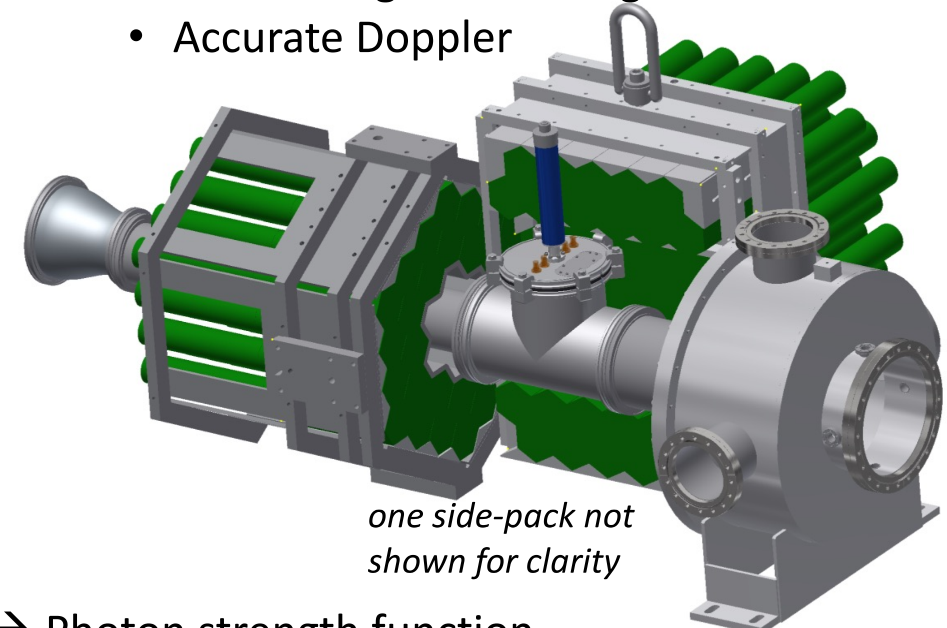
silicone oil coupling, quartz window, PMT





DAPPER

- (d,p) as (n,g) proxy
- highly segmented → Inverse kinematics → RIB
- Highly segmented, high efficiency
  - Excitation energy
  - Gamma multiplicity
  - Total gamma energy
  - Individual gamma energies
  - Accurate Doppler

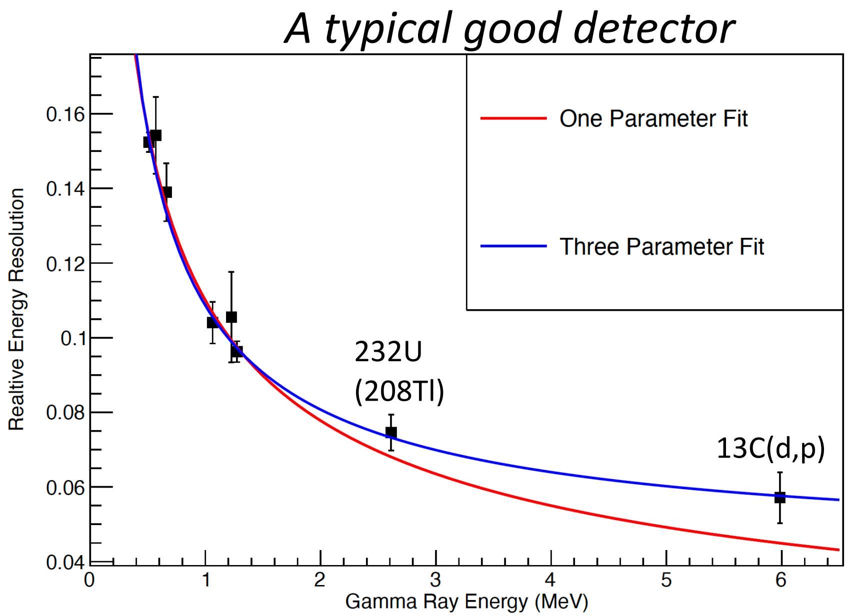


one side-pack not shown for clarity

→ Photon strength function

→ Improve neutron capture model predictions

Energy Resolution of DAPPER

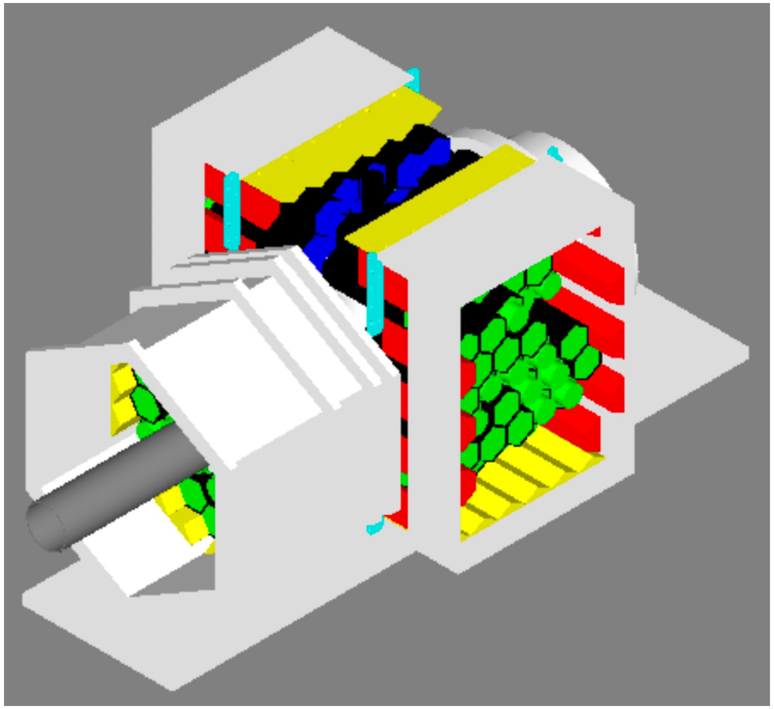


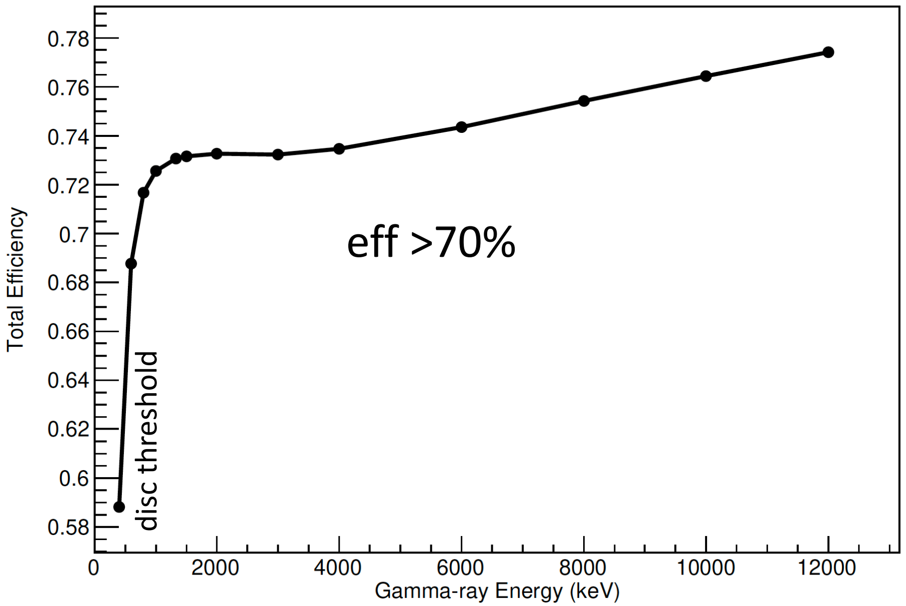
$$\frac{W(E_\gamma)}{E_\gamma} = \frac{\sqrt{aE_\gamma}}{E_\gamma}$$

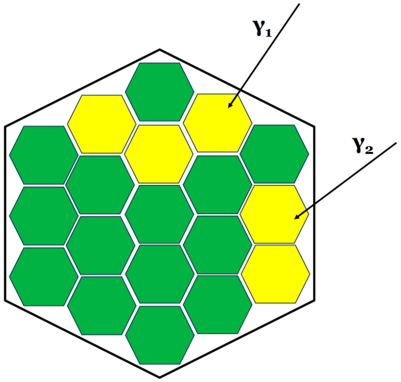
$$\frac{W(E_\gamma)}{E_\gamma} = \frac{\sqrt{a_0 + a_1 E_\gamma + a_2 E_\gamma^2}}{E_\gamma}$$

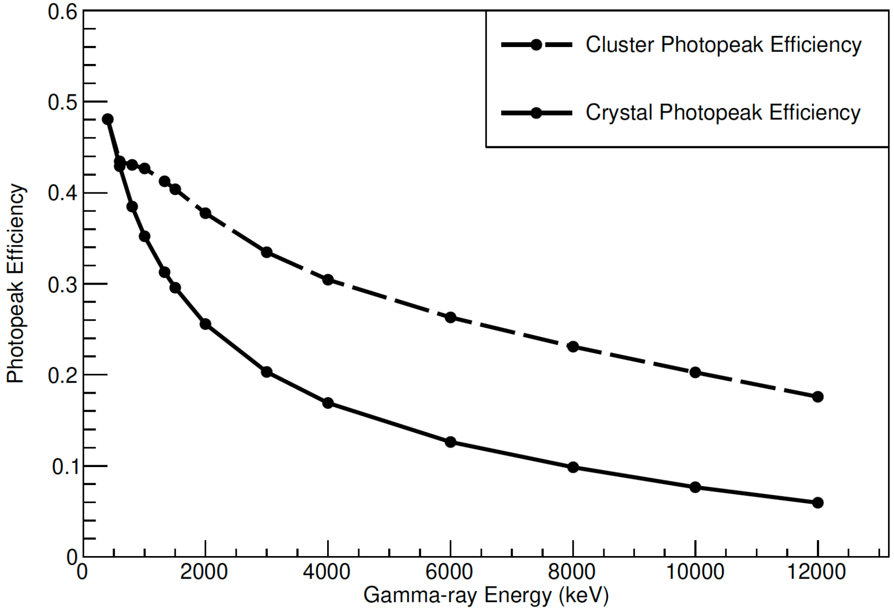
Nearly all detectors between 10-20% at 1 MeV.

Efficiency of DAPPER









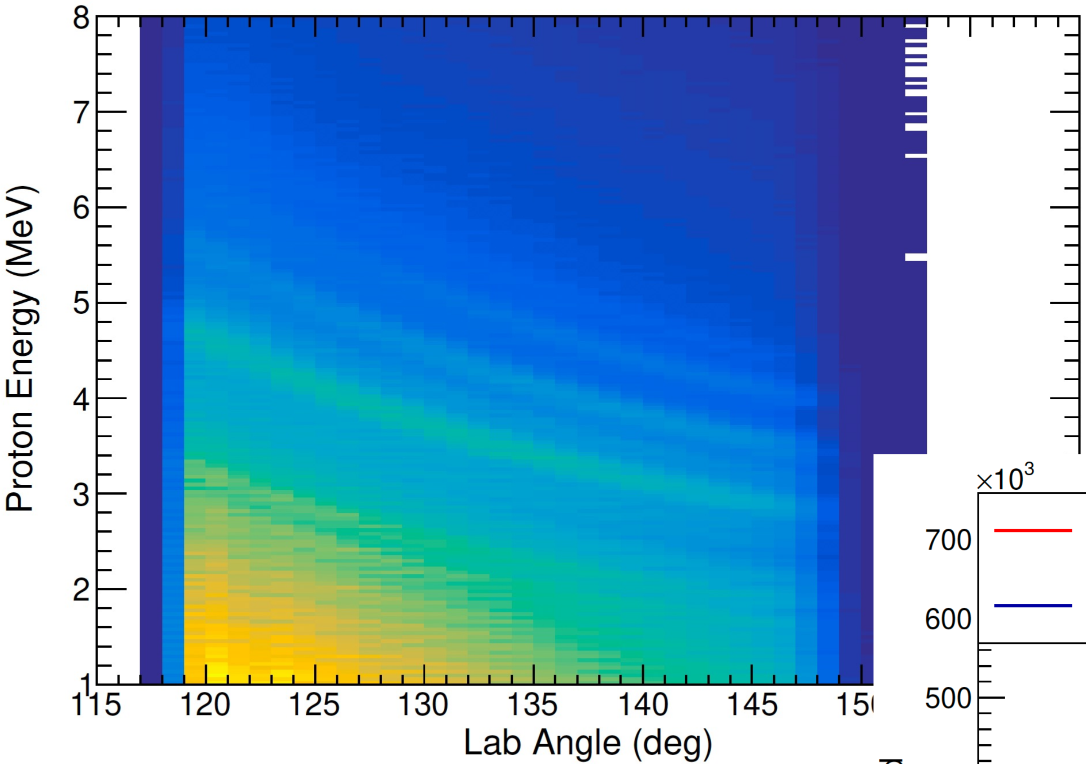
Commissioning and First Physics Measurement: 2021

57Fe(d,pg)

Excitation Energy

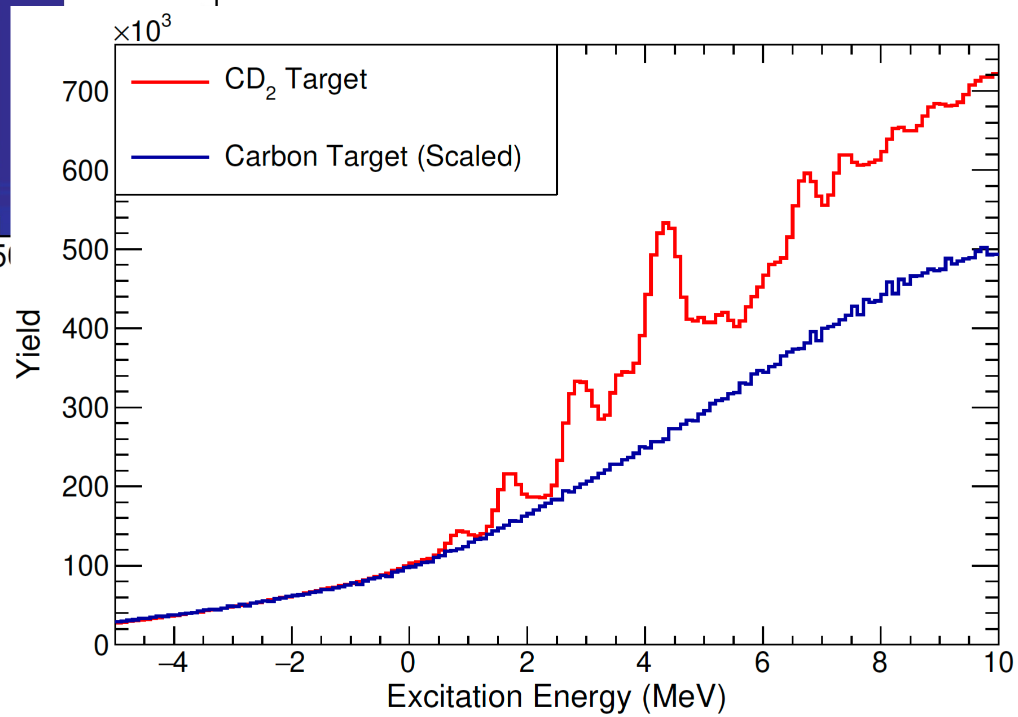
57Fe(d,pg)

Silicon (S3) coverage 120-150 degrees
Kinematic selection of transfer, not fusion-evaporation

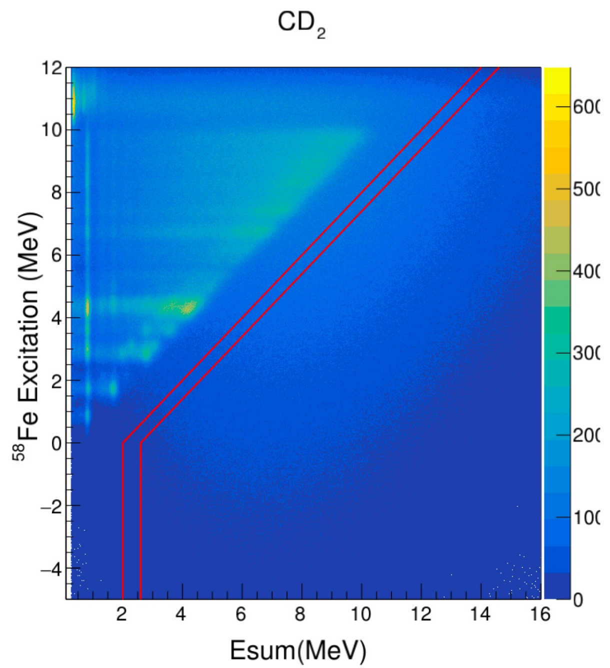


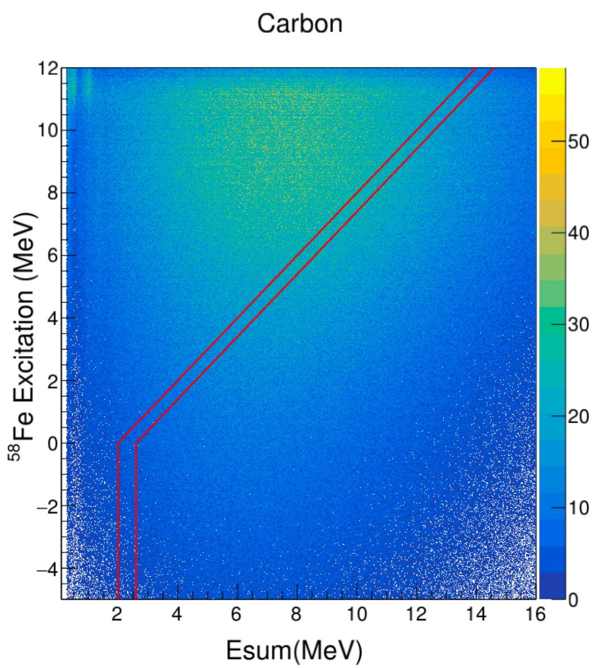
~500 keV E* resolution

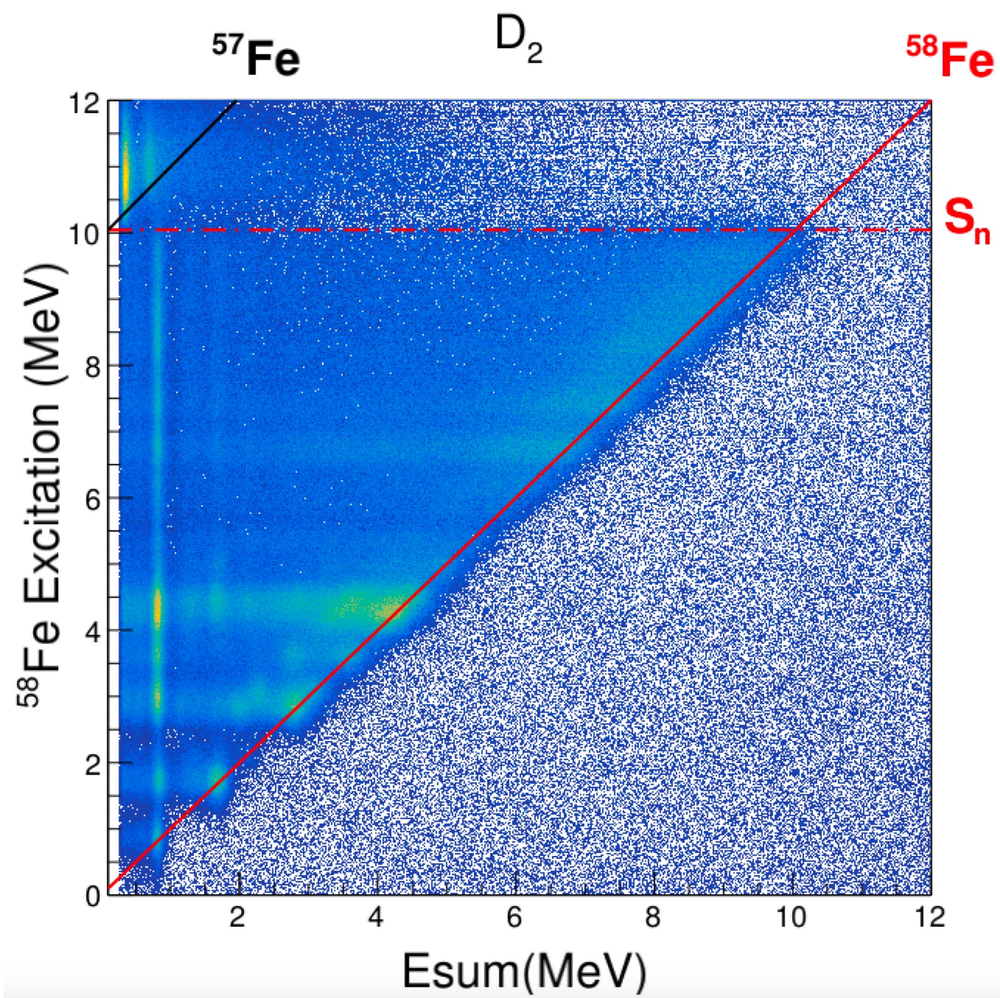
- target thickness
- beam diameter



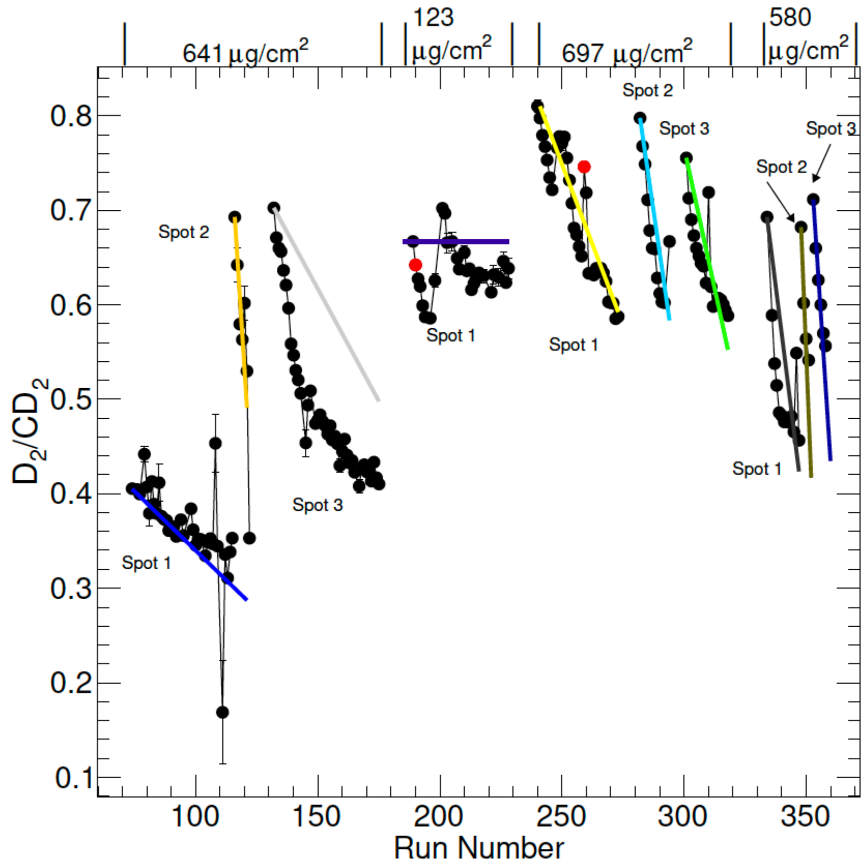
57Fe(d,pg) @ 7.5 MeV/u in DAPPER



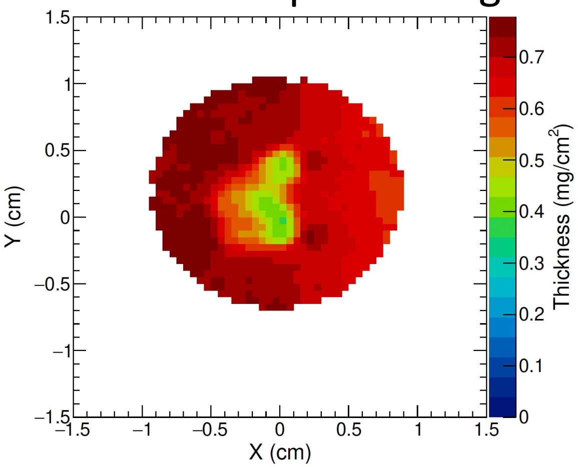


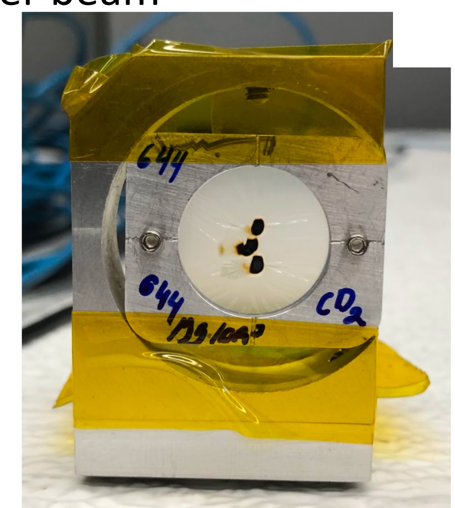


Correction for target thickness



Deuterated plastic target after beam





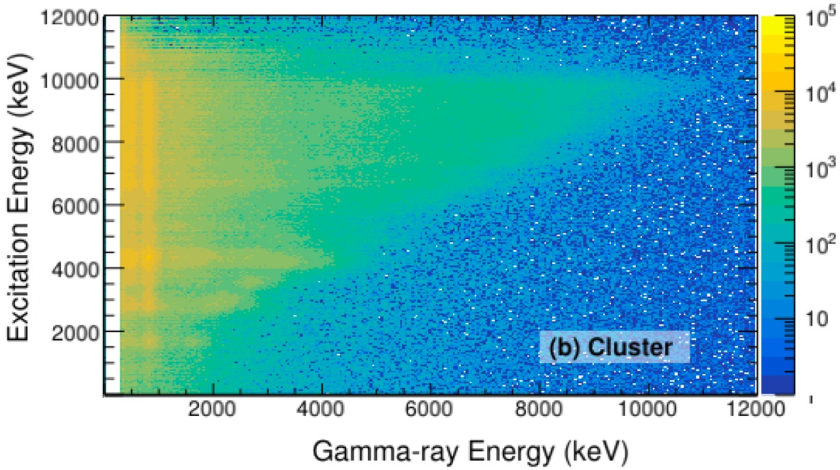
Deuterium loss over time
Deduced from peak (D2)
to peak+bkg (CD2)

Oslo Method: 58Fe Photon Strength Function

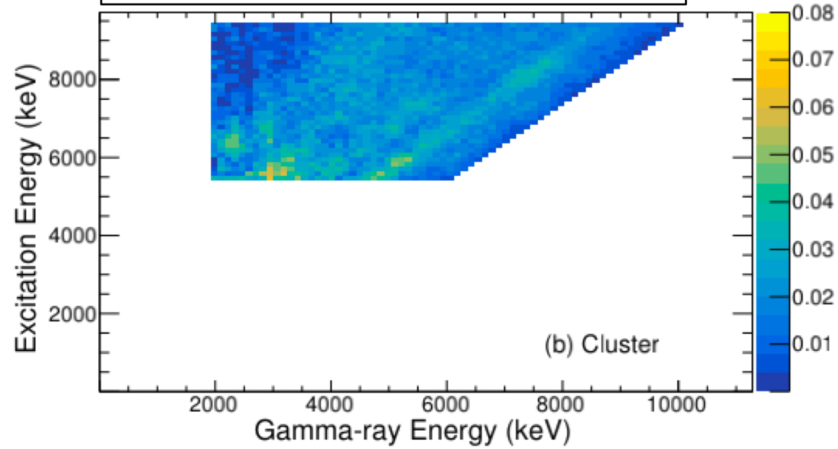
A. Abbott, Ph.D. Thesis, TAMU (2024)

A. Abbott

1. raw



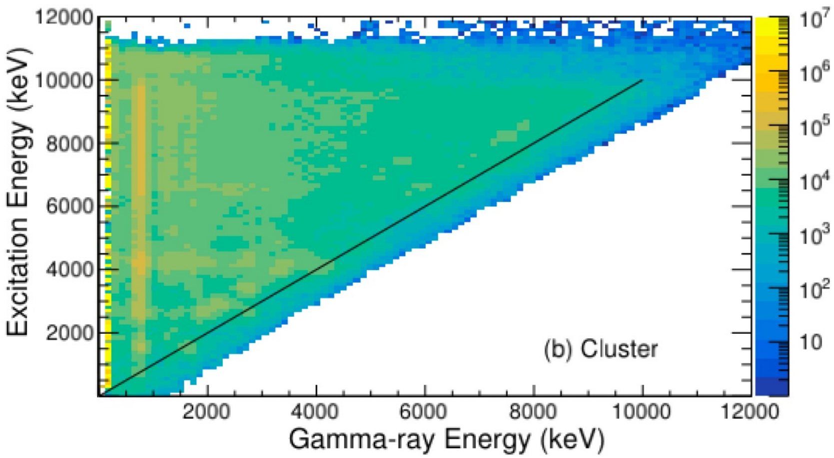
3. primary gamma rays only

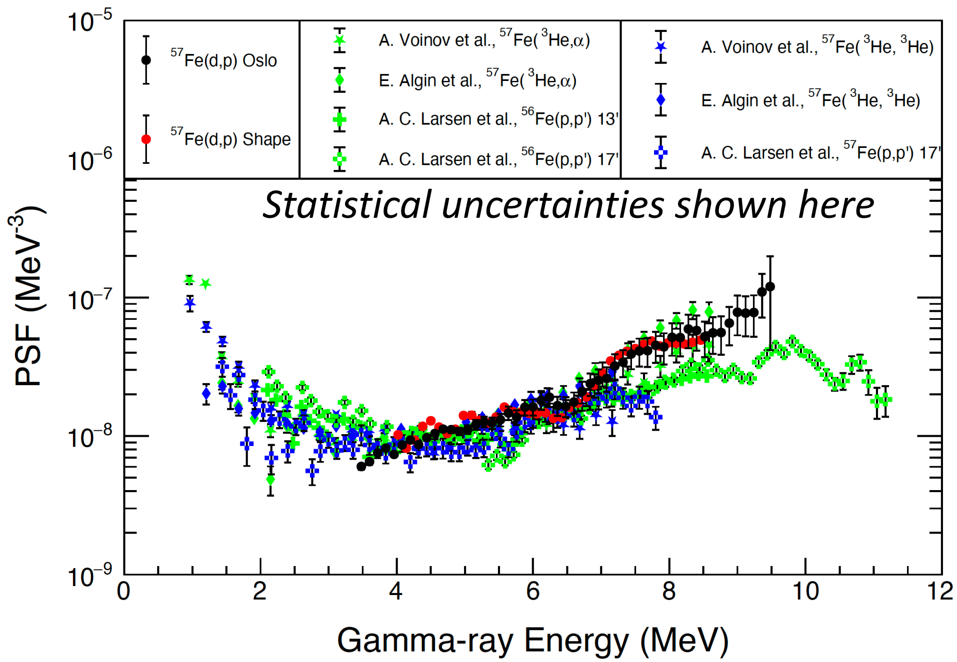


2. Doppler corrected “unfolded” remove detector response

Doppler: 22% variation!

*DAPPER **segmentation** allows **inverse kinematics***





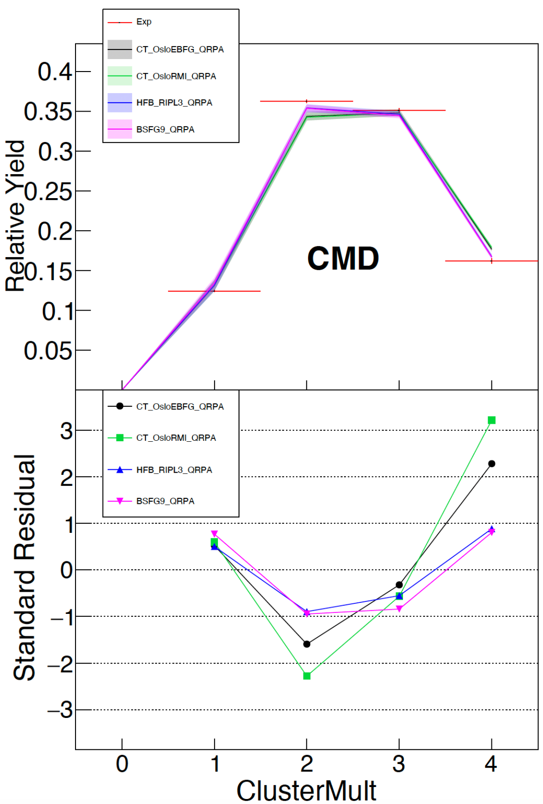
Forward Method

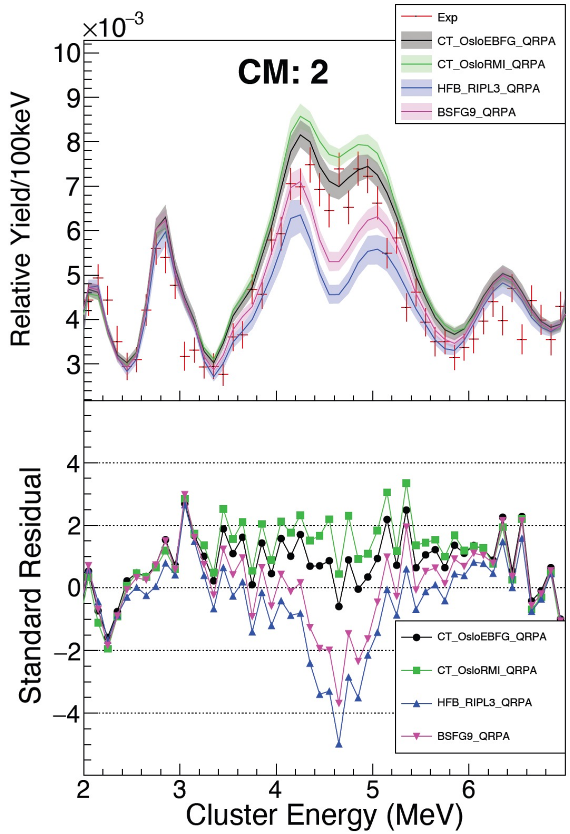
57Fe(d,pg)58Fe@ 7.5 MeV/u

M. Sorensen

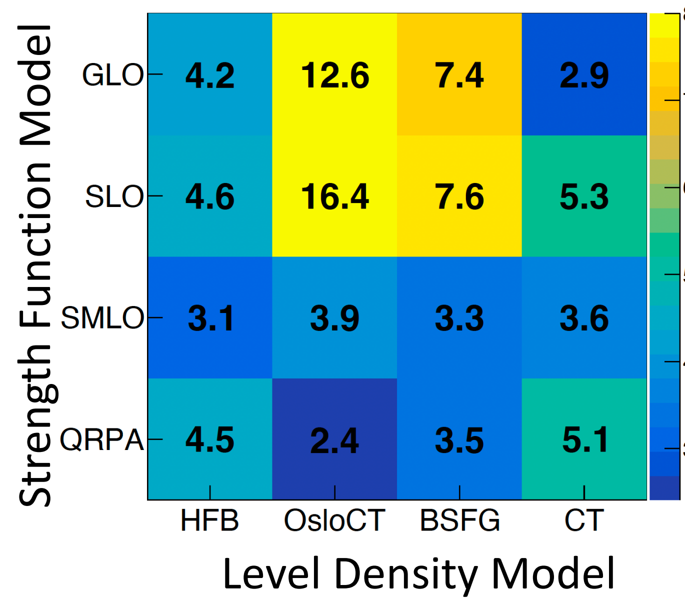
1a) Pick a PSF
1b) and pick a NLD
2) Simulate many 58Fe nuclei deexciting
3) Filter with detector response
4) Compare sim to exp:

also compare:
Energy Dist for Mult=3
Energy Dist for Mult=4



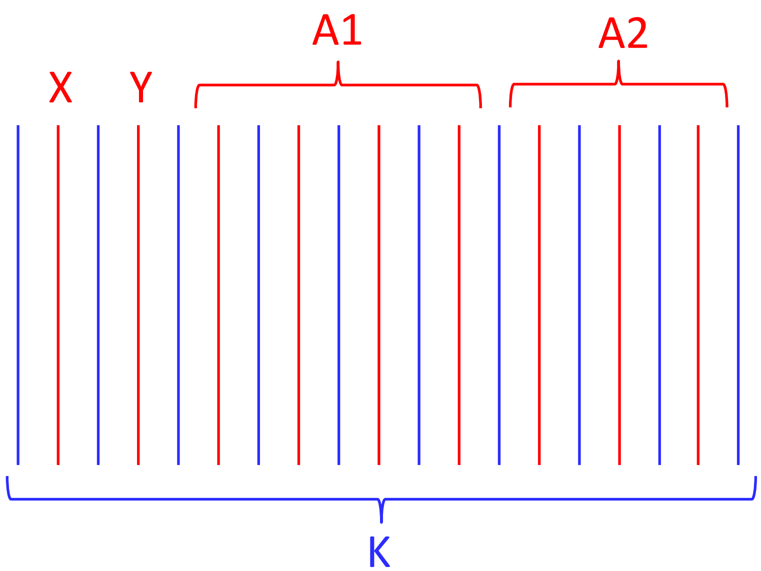


Model Agreement: χ2/N



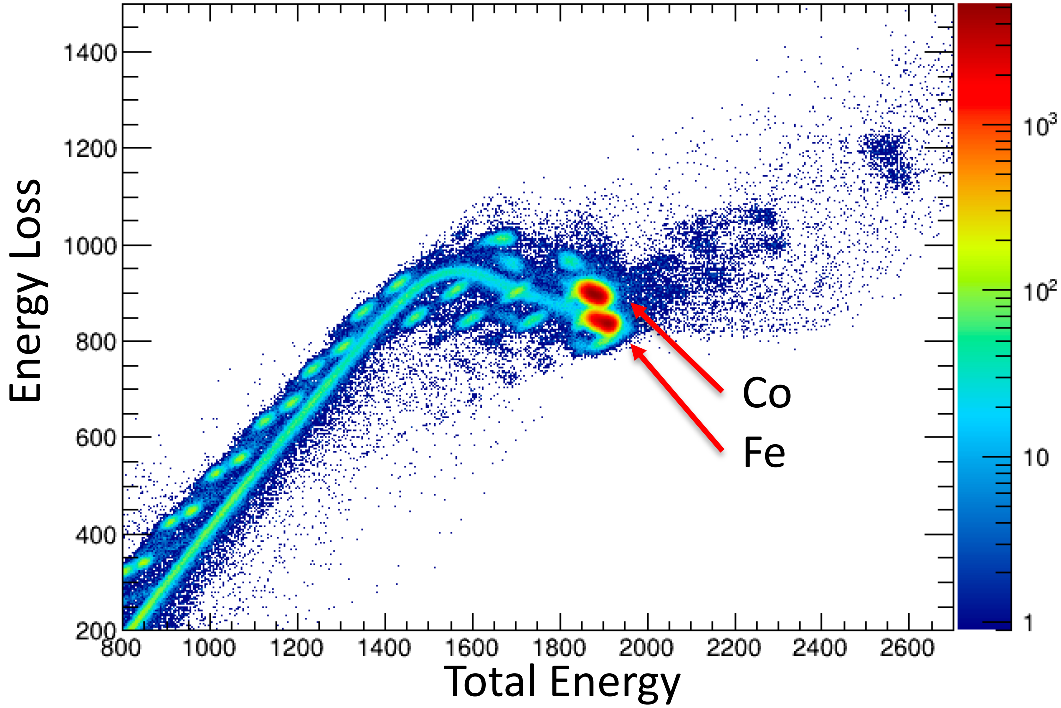
Zero-degree ionization chamber

In collaboration with S. Pain (ORNL) et al., GODDESS IC
S. Pain, T.T. King, M. Grinder, S. Balakrishnan (ORNL)
A. Ratkiewicz, R. Ghimire (LLNL)



~100 Torr C4H10
Wire planes, 99% transmission
Close spacing of wire planes
Fast preamplifiers, fast shapers
→ High Rate

Nov 2023 Measurement @ TAMU
Fe/Co cocktail beam



Unit Z separation
> 5e5 pps
dE-E technique

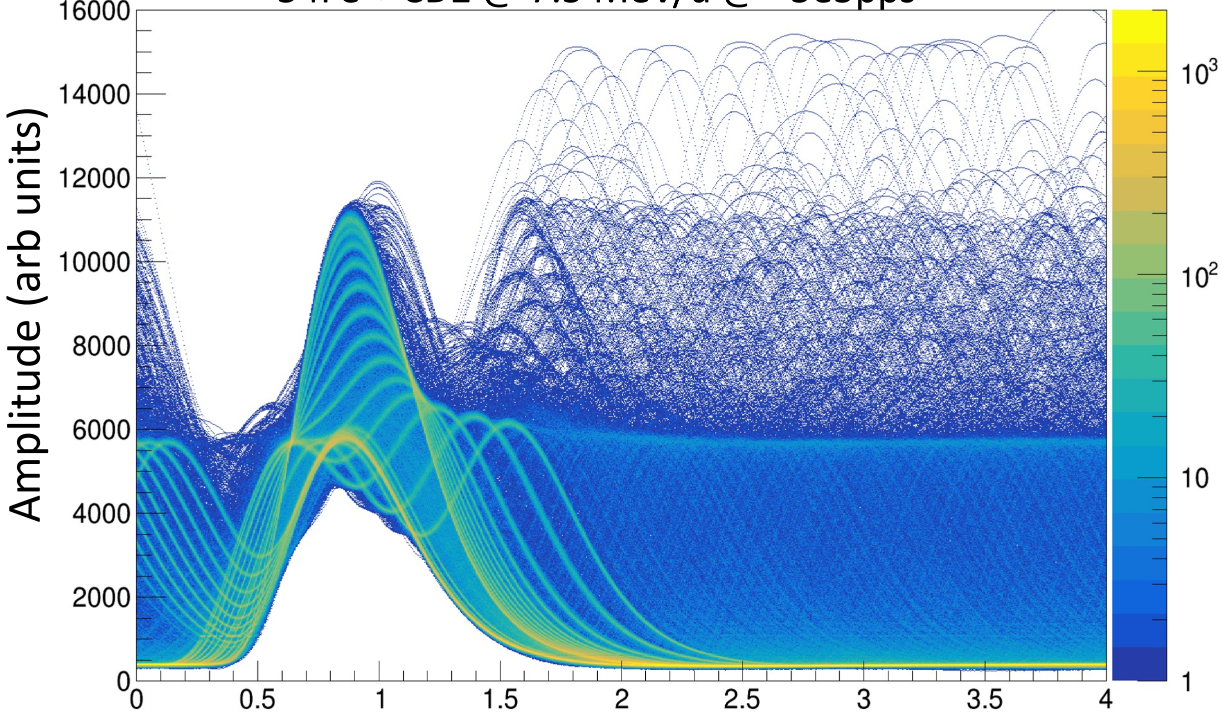
<u>other <= 1% features</u>
slit-scattering
stopping in wires
pile-up
combinations of these

Zero-degree ionization chamber

Arthur Alvarez

December 2023
Measure 54Fe(d,pg)55Fe with DAPPER
Residues at 0 deg in IC

54Fe + CD2 @ 7.5 MeV/u @ ~5e5pps



time (us)

GODDESS IC Cathode (tot ene)
-> Preamplifier
-> Shaper
-> Waveform Digitizer

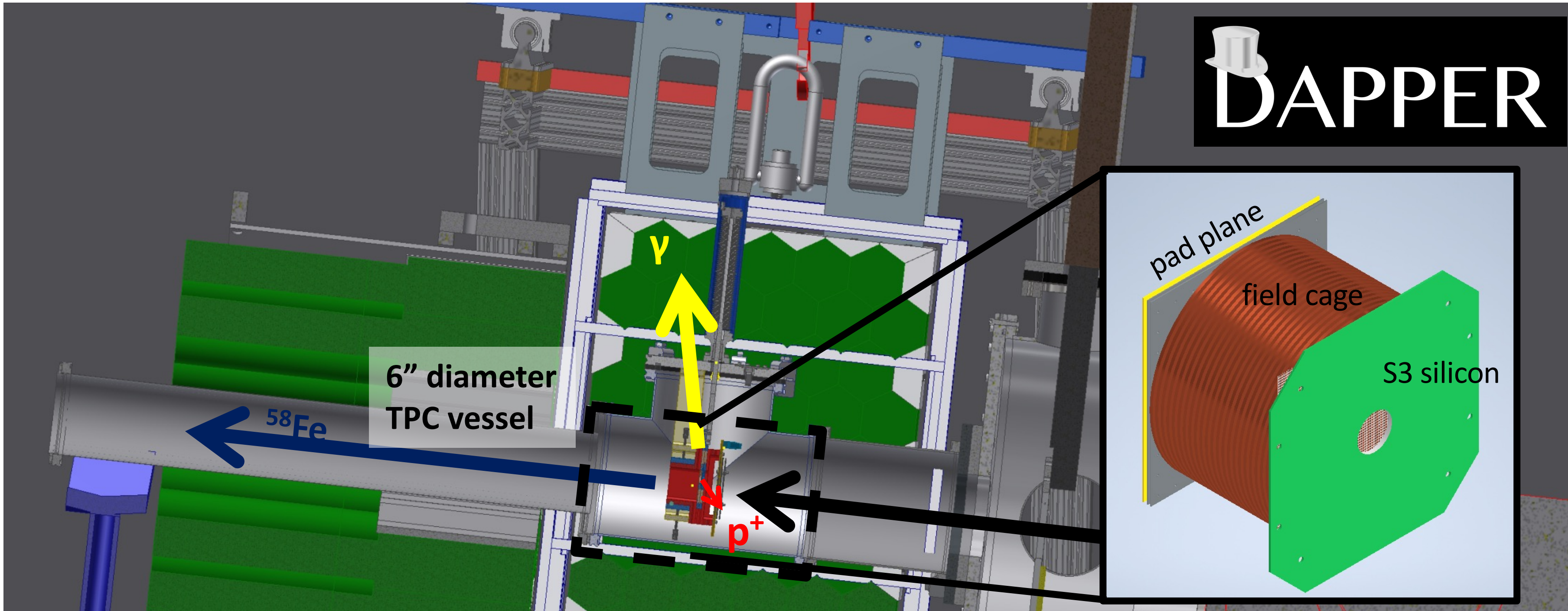
Pileup Clearly Observed and distinguishable

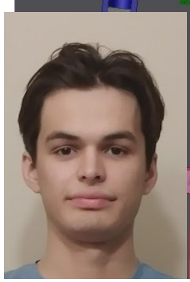
Deconvolute to improve efficiency at high rate

TPC for DAPPER

Simulations in progress
10cm length x 10cm dia

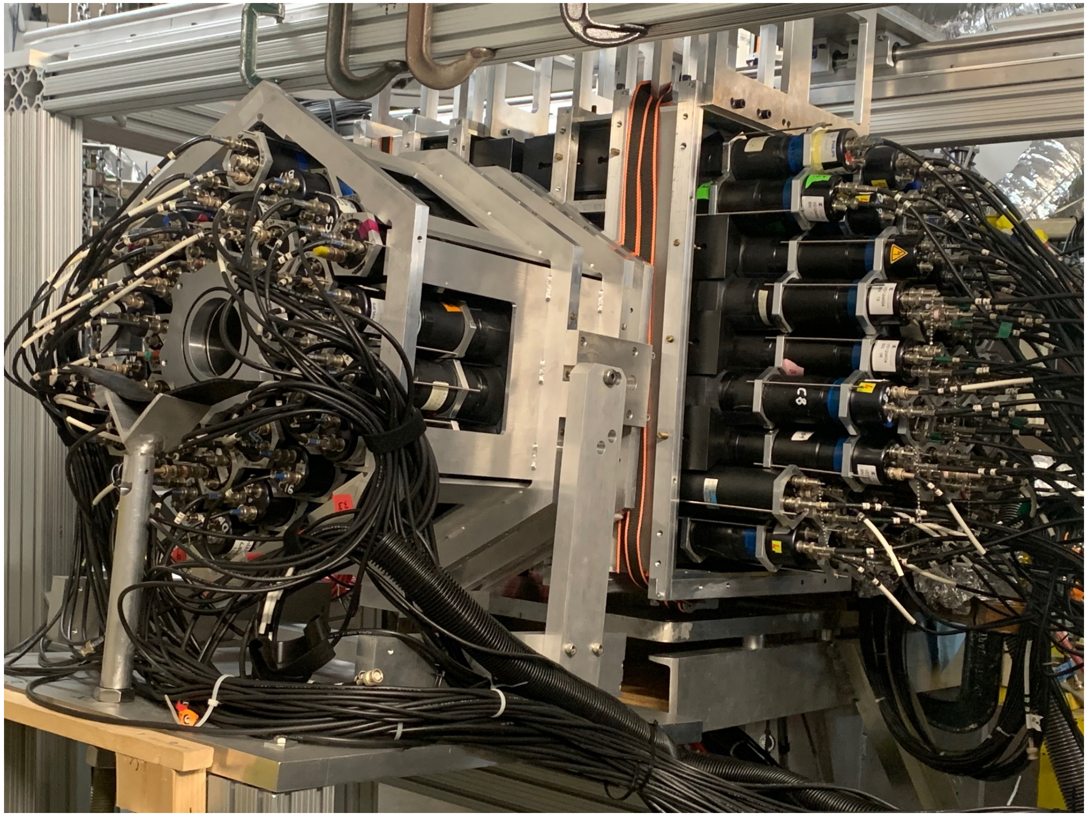
- no fusion-evaporation background
- no target degradation
- higher density of deuterium
- improved E* resolution (energy loss and angle)





Sebastian
Regener

DAPPER



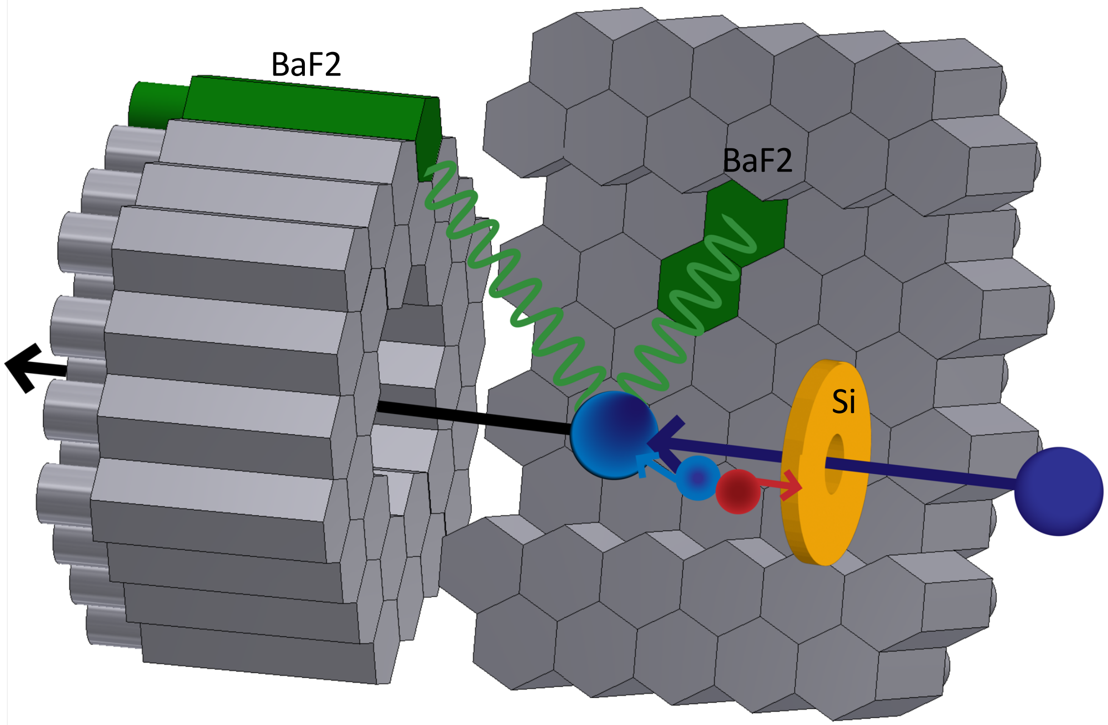
<u>Capabilities</u>

High Gamma Ray Efficiency
High Granularity
Total Gamma Energy
Gamma Multiplicity
Individual Gamma Energy
Good Doppler Correction
Inverse Kinematics
Secondary Beams
Unit-Z for Residues at High Rate

Fin

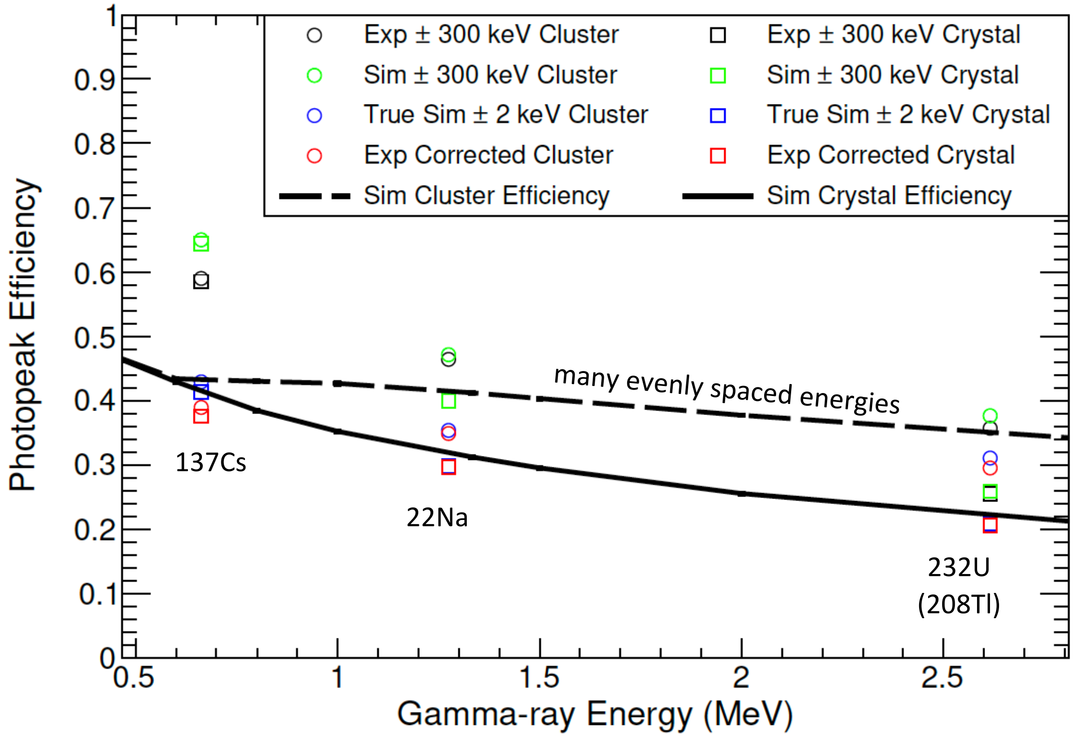
Backup slides

Detector Array for Photons, Protons, and Exotic Residues

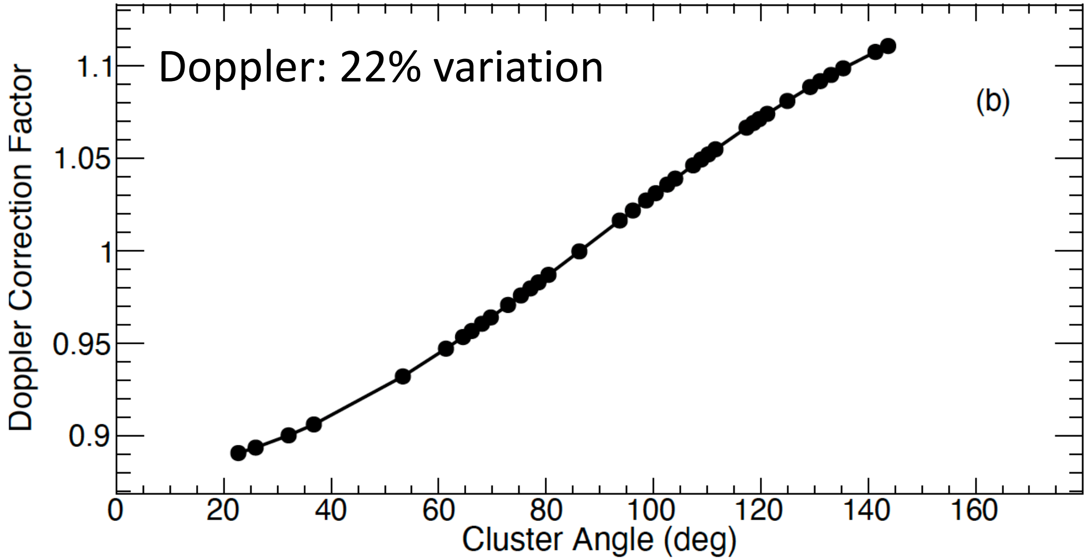


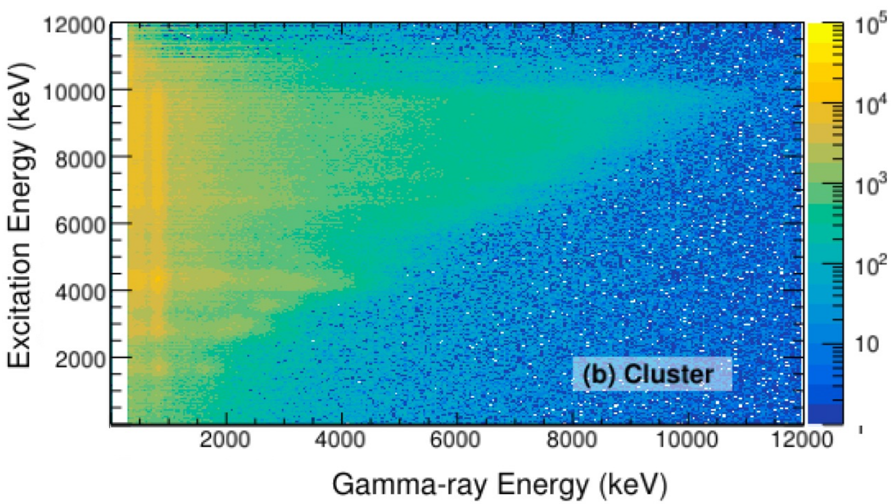
one side-pack not shown for clarity

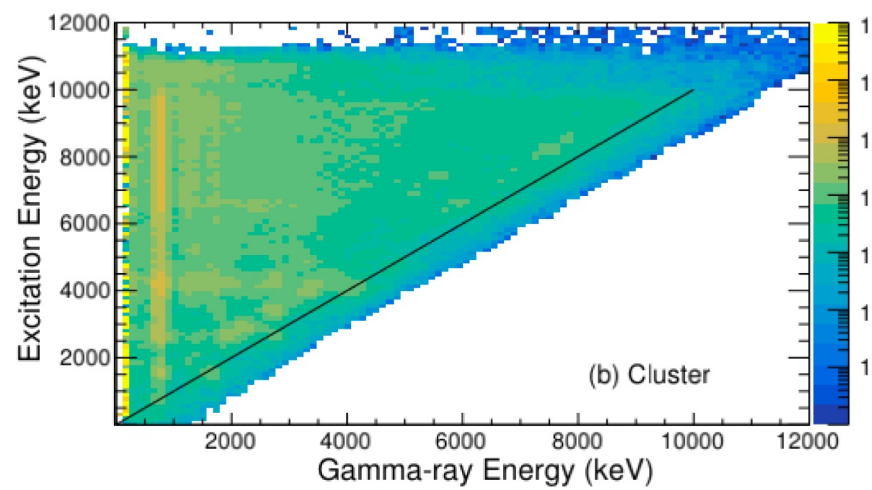
- (d,p) as (n,g) proxy
- highly segmented → Inverse kinematics → RIB
- Highly segmented, high efficiency
  - Excitation energy
  - Gamma multiplicity
  - Total gamma energy
  - Individual gamma energies
  - Accurate Doppler
- Photon strength function
- Improve neutron capture model predictions



- measured. includes some Compton scattering
- simulation, to compare to measured
- simulation. narrow gate to exclude all Compton
- experiment corrected by ○/○







1. raw

2. Doppler corrected
“unfolded” remove
detector response

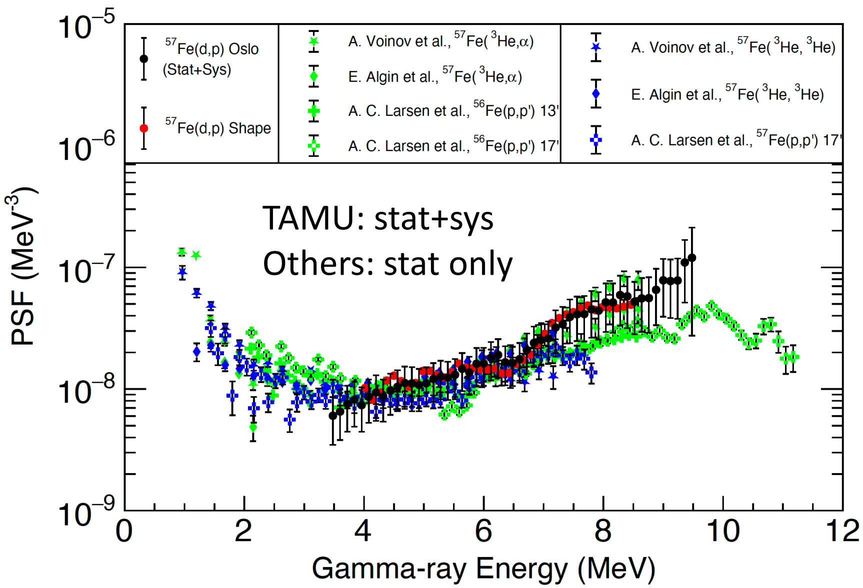
58Fe Photon Strength Function

A. Abbott, Ph.D. Thesis, TAMU (2024)

see also M. Sorensen Ph.D. Thesis, TAMU (2024 in prep)

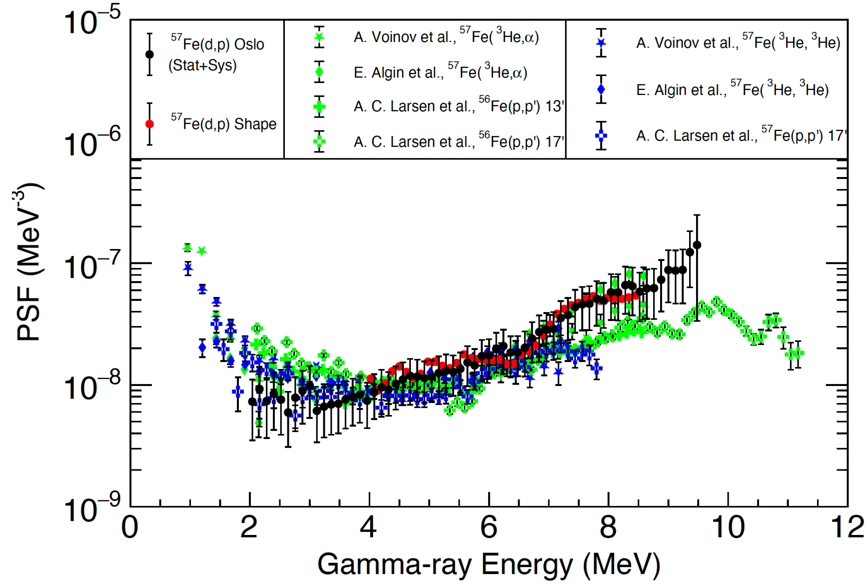
A. Abbott

Inclusion of data down to 3.5 MeV

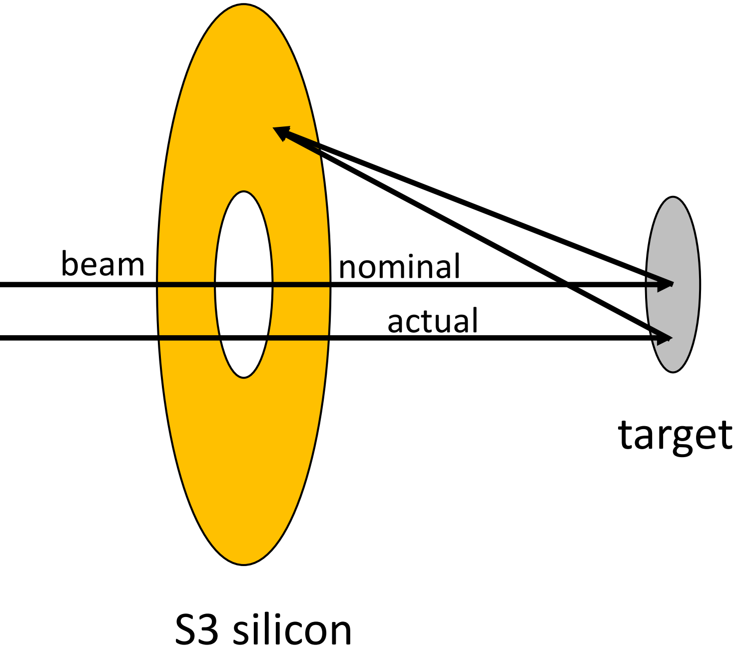


no evidence of low-energy enhancement down to 3.5 MeV

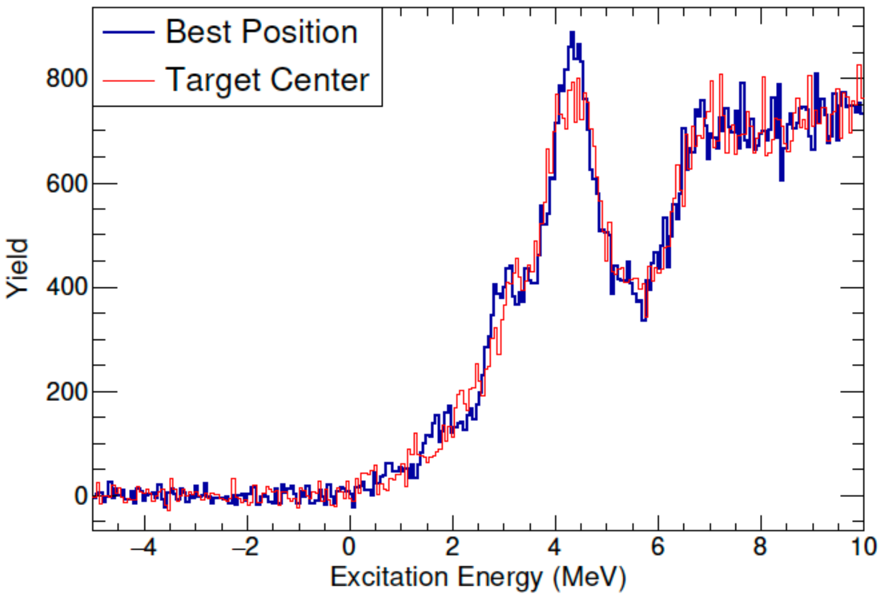
Inclusion of data down to 2 MeV

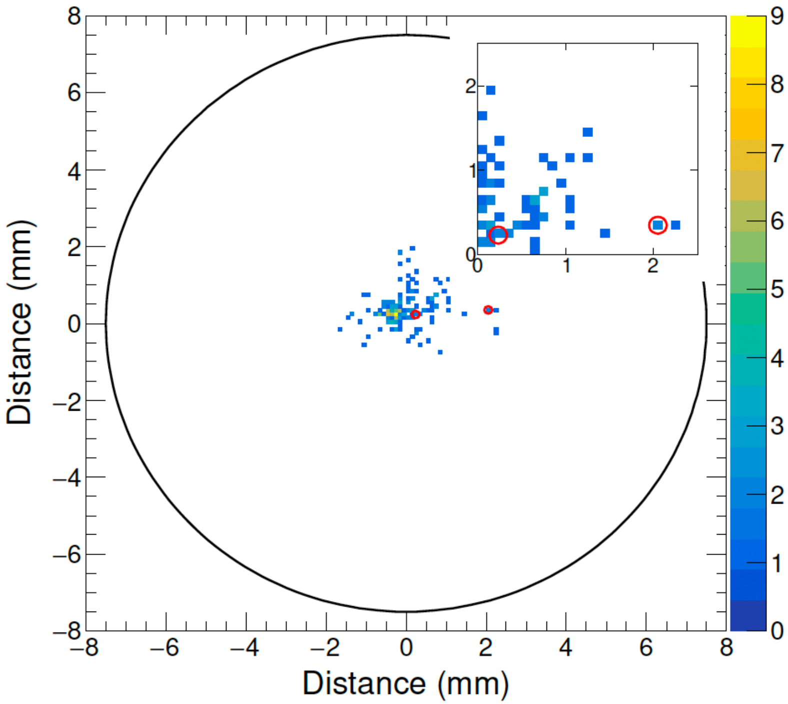


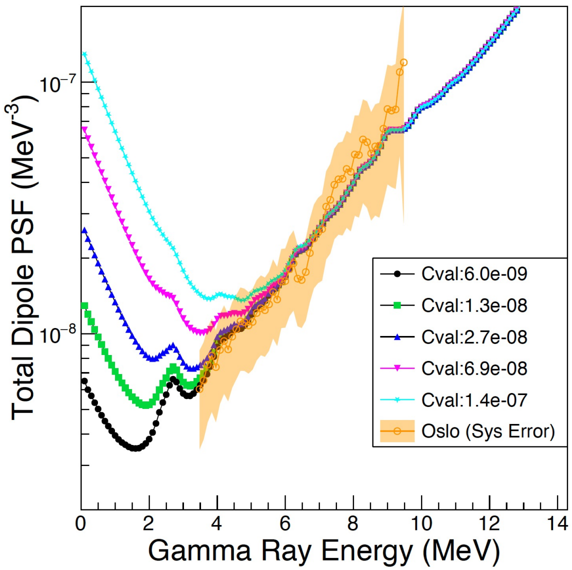
no evidence of low-energy enhancement down to 2.0 MeV, though non-statistical population of low states may obscure

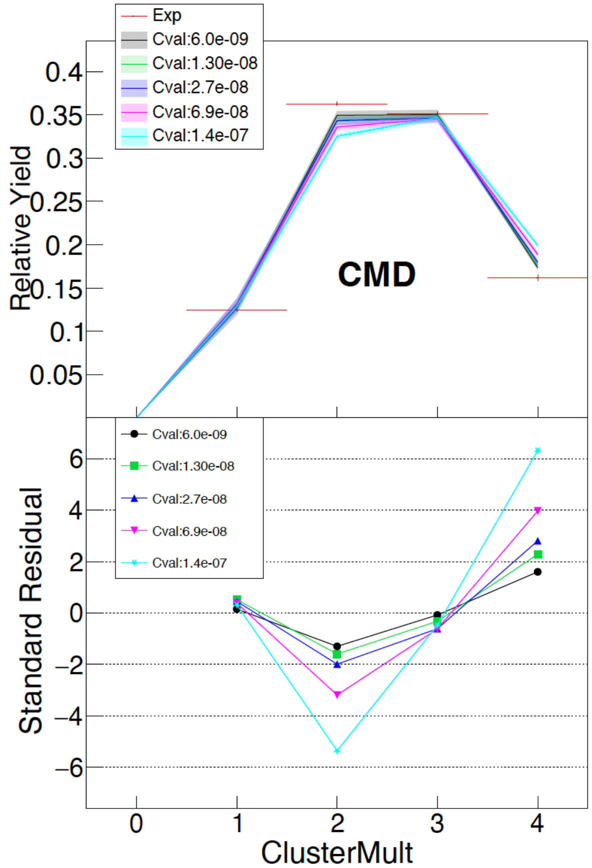


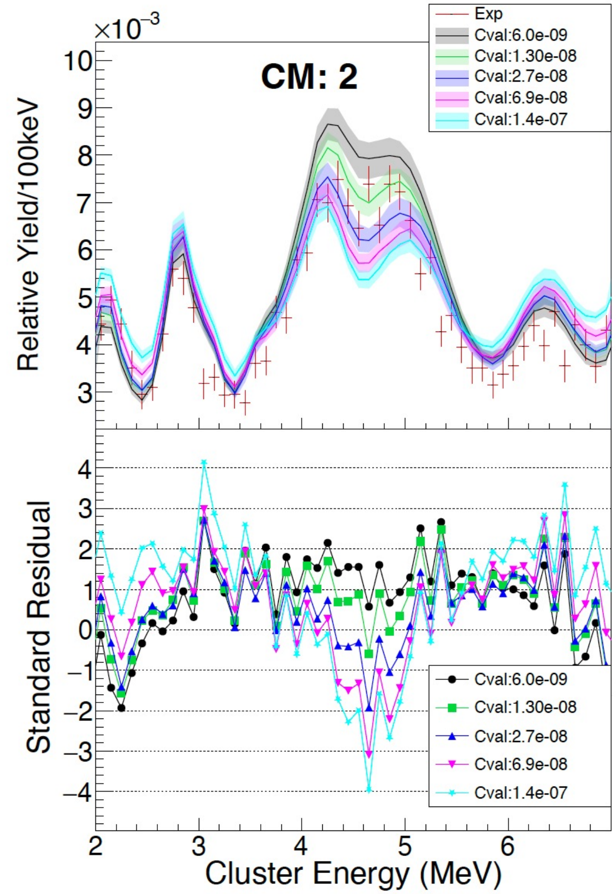
beam spot → angles → E*











1) vary the low energy enhancement in the PSF
2) simulate many 58Fe deexcitation cascades
3) filter for detector response
4) compare simulation and experiment

Rule out large (but not small) low-energy enhancements

M. Sorensen

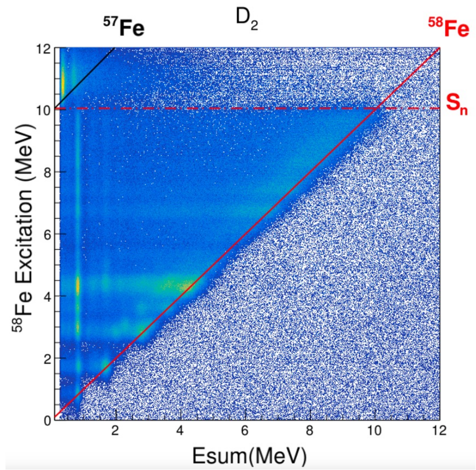
DAPPER

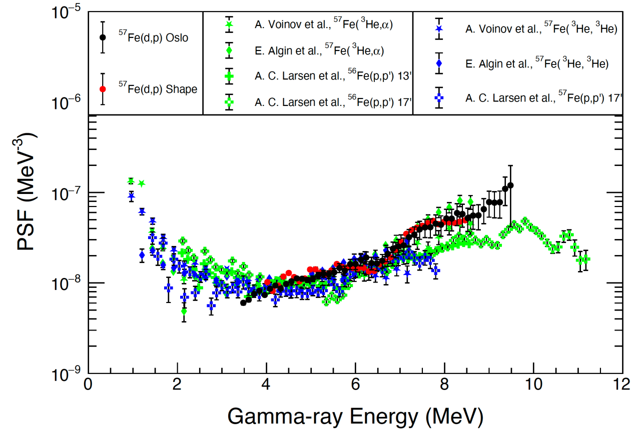
Successes, to date

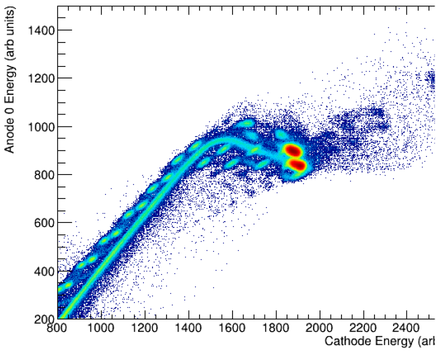
Measurement of 57Fe(d.pg)58Fe
One Ph.D. completed (A. Abbott)
One Ph.D. dissertation in progress (M. Sorensen)
Two PRC and one NIM in preparation
Photon strength function of 58Fe measured

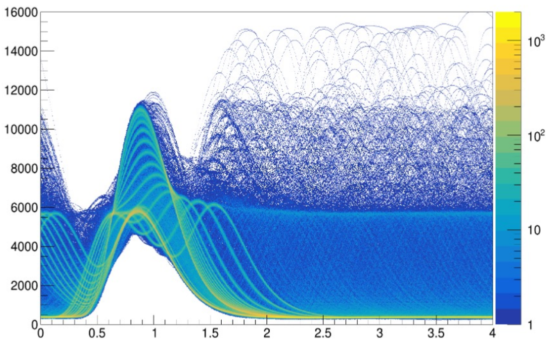
Zero-degree residue detector demonstrated
Measurement of 54Fe(d,pg)55Fe (A. Alvarez)

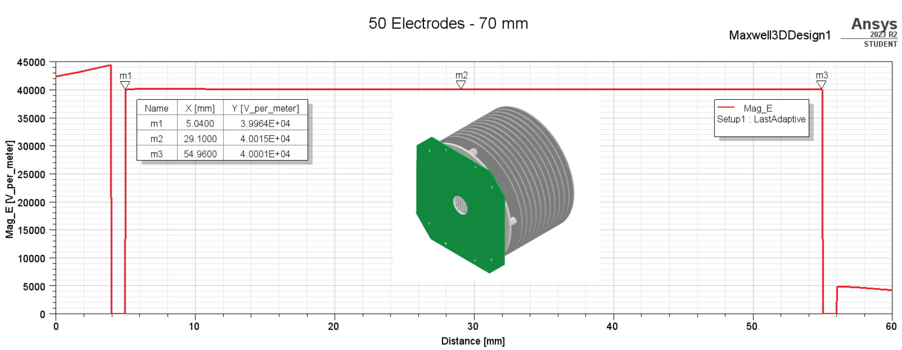
Field simulations for DAPPER TPC made (S. Regener)











TALYS predictions incorporate 9PSF x 6NLD = 54 combinations

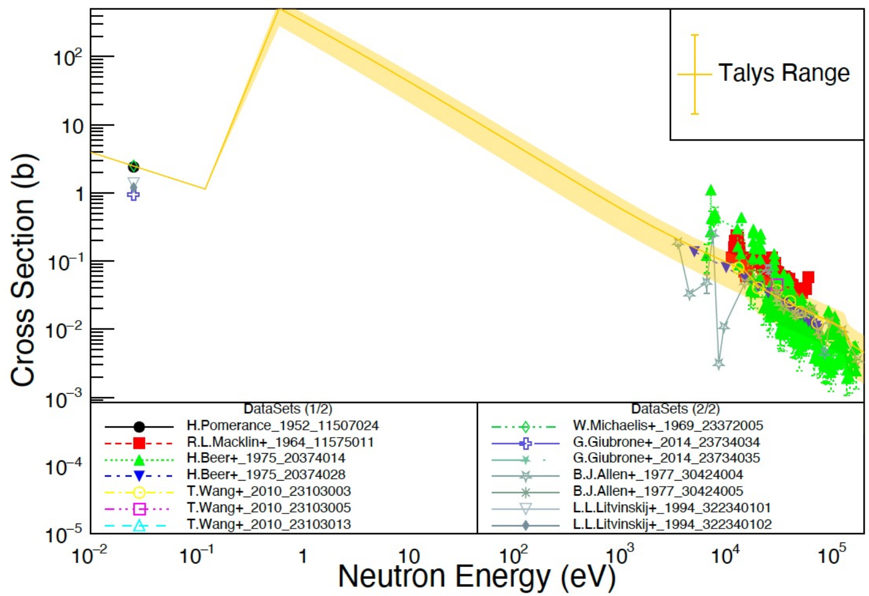


Figure 8.16: Neutron capture cross sections for the $^{57}Fe(n,g)^{58}Fe$ reaction, taken from the EXFOR database. Numerous measurements were made for different incident neutron energies. Each dataset is labeled with the first author, the date of publication, and the dataset ID in EXFOR. Some points do not have reported error bars for them. Talys predictions are shown as the orange region, with the width of the region denoting the range over which TALYS predicts for all built-in combinations of E1 PSF and NLDs.